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(54) Stator core for a  
dynamoelectric machine

(57) A dynamoelectric machine having a laminated core 10 comprises a plurality of annular laminations 12. Each lamination is edge rolled from straight strips of magnetic material with teeth 14 punched into one edge. each lamination is slightly less than 360° in arcuate length, leaving a

slight gap 18 between its ends to allow the finished core to be accurately sized by compressing its outer surface. By punching the straight strips from sheet metal in such a way as to orient the grain structure in the direction of tooth extension and edge rolling the opposite edge, a selective grain orientation can be achieved which is magnetically advantageous throughout the core.

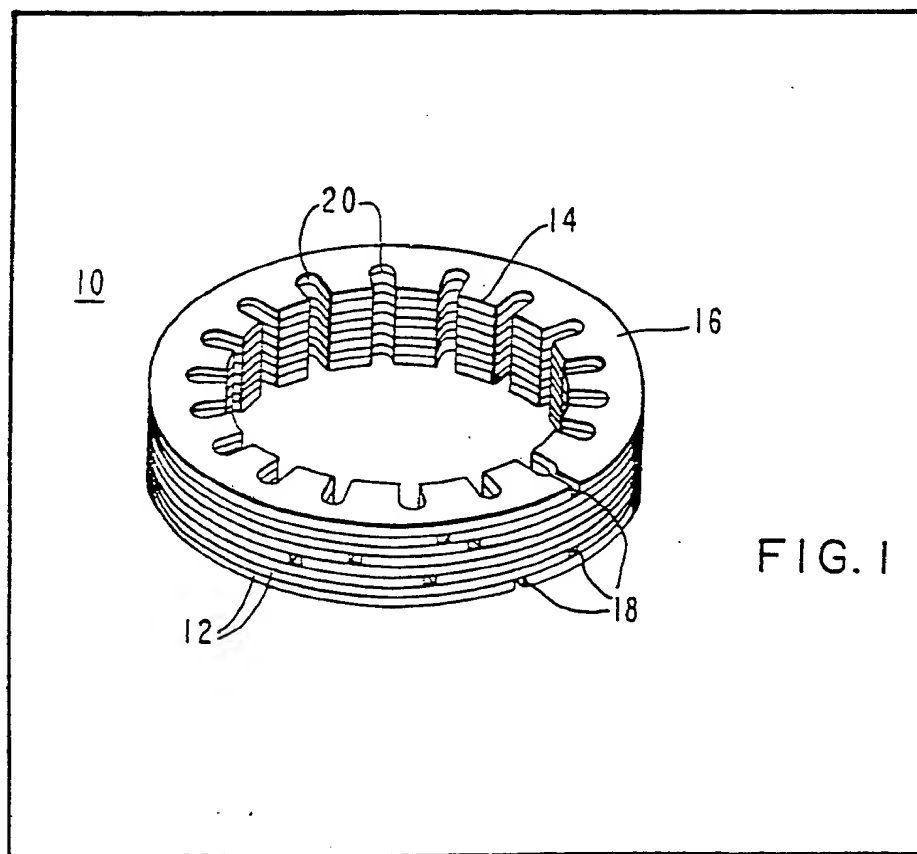


FIG. 1

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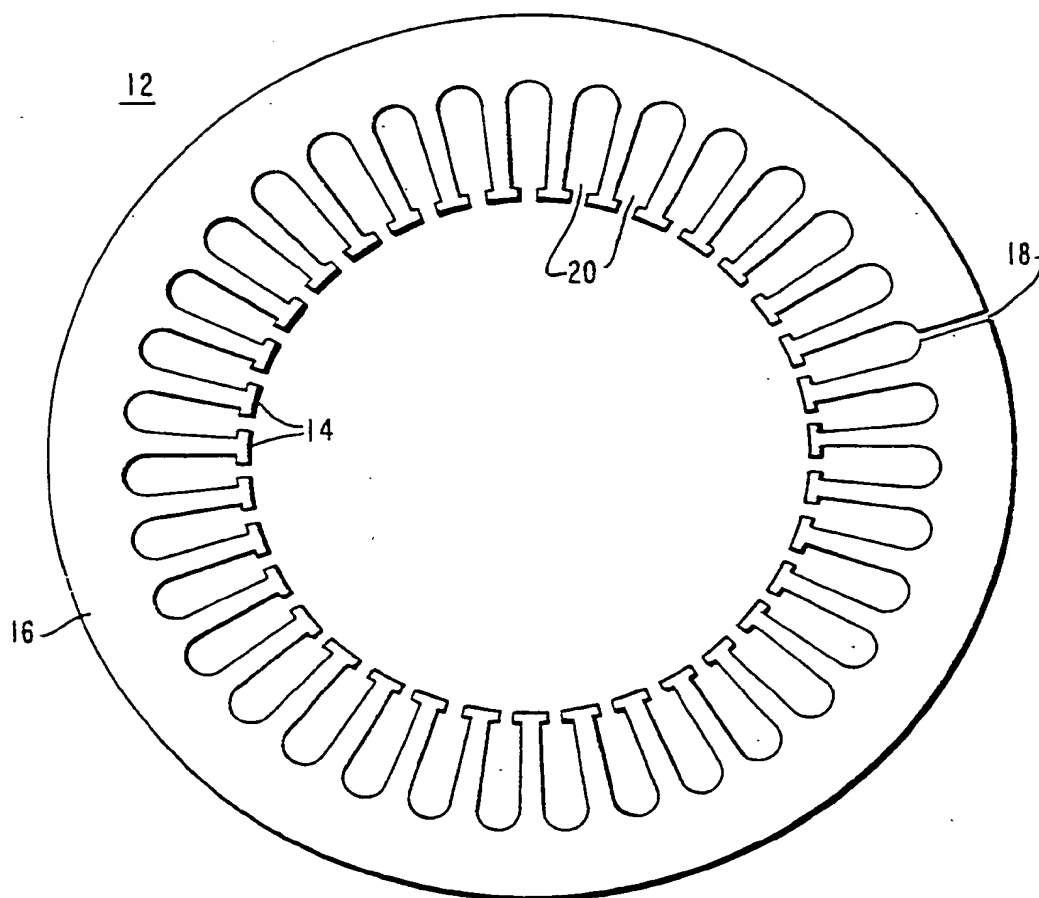
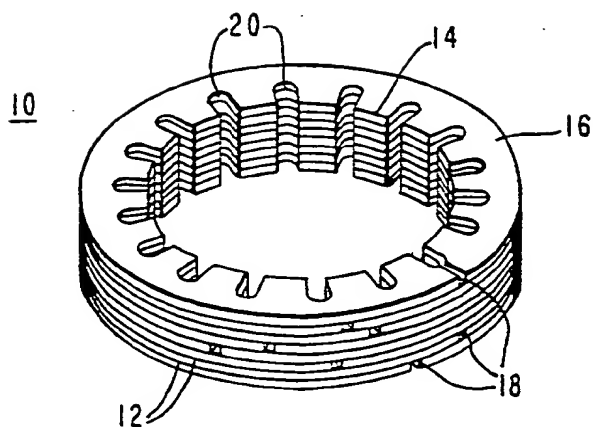


FIG. 3

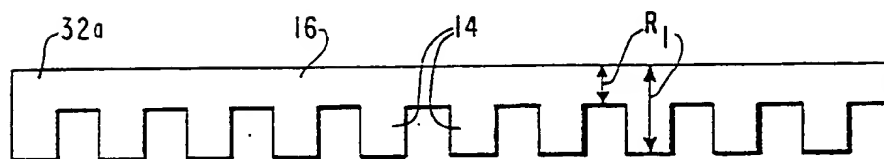
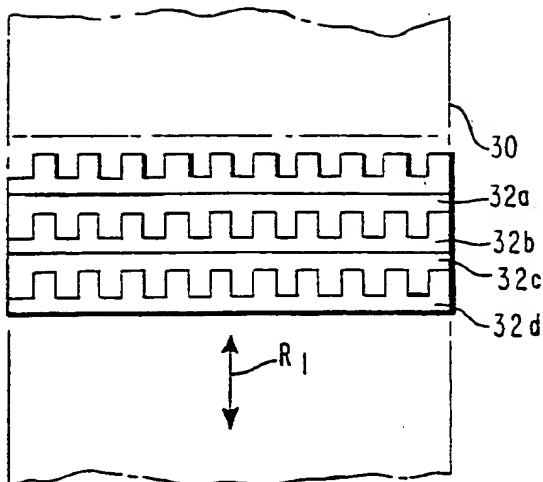


FIG. 4A

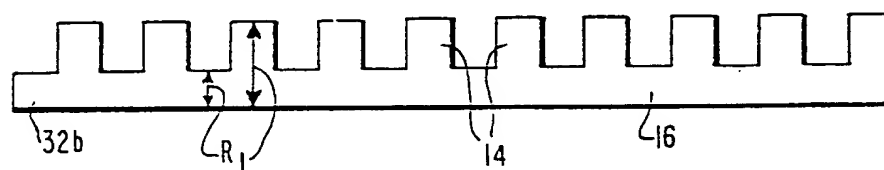


FIG. 4B

FIG. 5

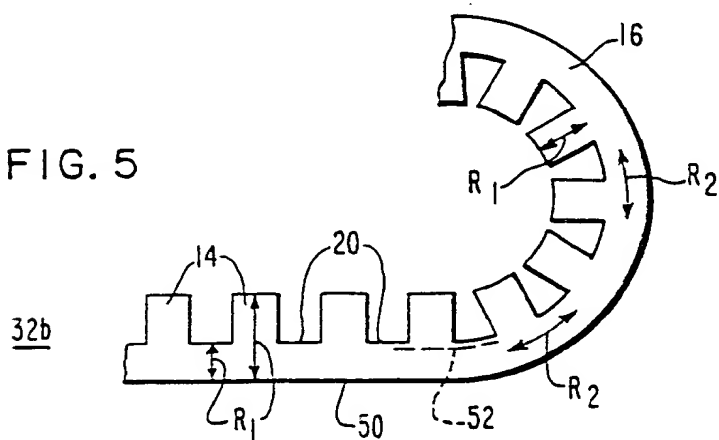


FIG. 6A

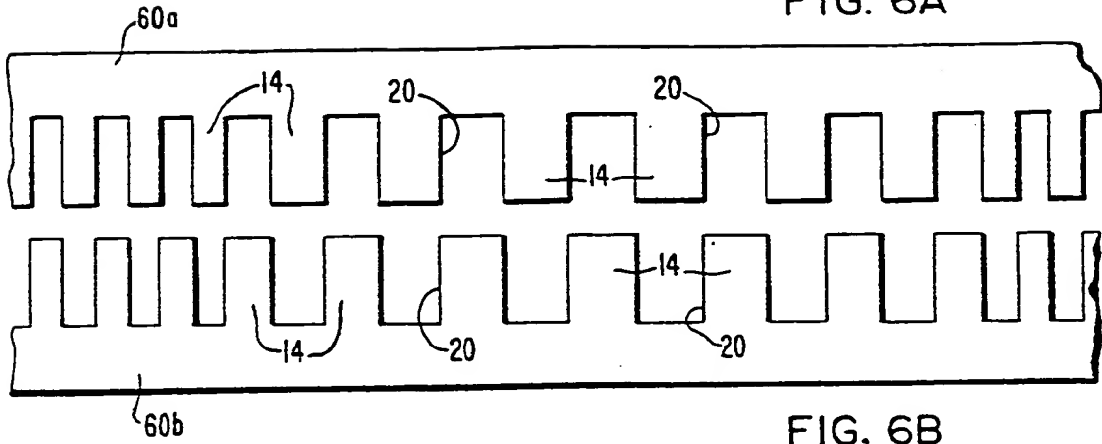


FIG. 6B

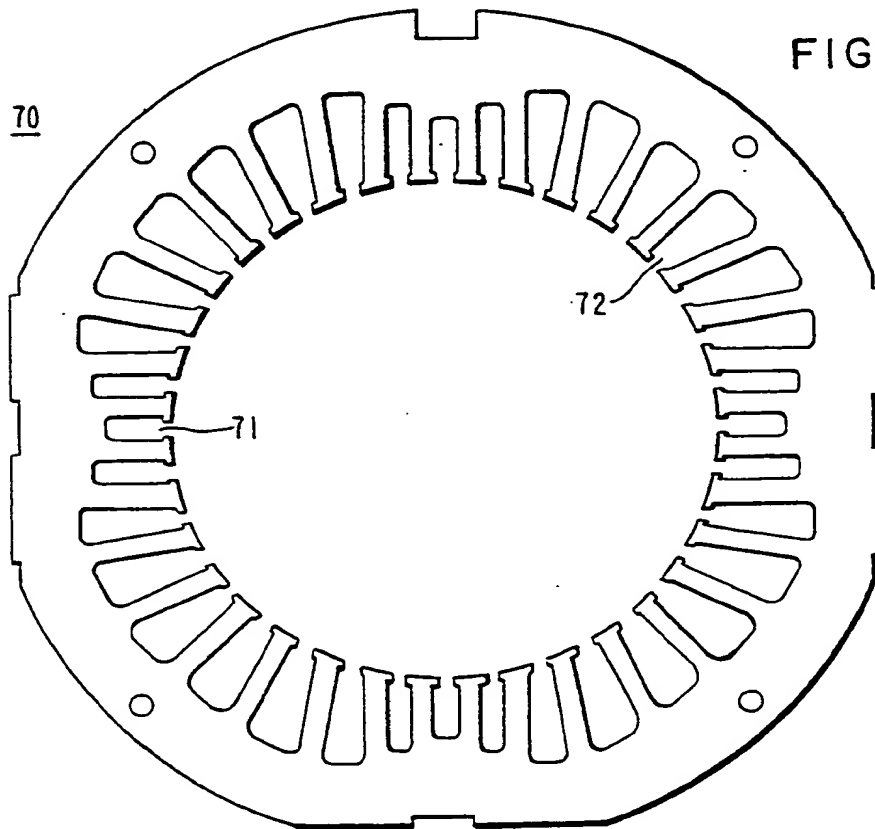


FIG. 7

## SPECIFICATION

## Improvements in dynamoelectric machines

This invention relates to a dynamoelectric machine, and in particular to stator cores of each machine. Stator cores of dynamoelectric machines are conventionally produced by stamping a plurality of annularly shaped pieces from sheet metal and stacking them together to form a cylindrical core with a coaxial bore therethrough. Typically, the punchings have teeth extending radially inward which are aligned with similar teeth of other punchings to form axially running slots in the bore of the cylindrical core. At a later stage of manufacture, conductors are disposed in these slots to form the stator winding of a dynamoelectric machine.

This process is inherently wasteful since the stamping of circular components from sheet metal creates scrap between adjacent circular punchings and between the teeth of each punching. In most situations this scrap is useless for any alternate purpose and, therefore, adversely affects the manufacturing costs of the stator cores.

A means to avoid this high percentage of wasteful scrap has been developed and consists of edge rolling a band of material into a helical shape. This process is described in the Specification of U.S. Patent Nos. 1,920,354, 3,845,647, 3,464,101, 3,062,267 and 3,152,629. These patent specifications all wind helical cores from a continuous strip of material by rolling the strip on its edge. Some of these utilize a shaping means that exerts a radially inward force on the strip to bend it into a circular shape while others, use forming rolls to cause the outer edge of the helical winding to be rolled to a thinner cross-section than the inner edge. This thinning operation causes the strip to curl into a circular shape.

The specification of U.S. Patent No. 4,116,033 describes an apparatus and method for forming a wound core which does not result in an outer lamination edge which is thinner than its inner portion. This patent also describes a tooth-slot nesting arrangement for punching its straight strip to minimize scrap material. An apparatus for continuously winding helical cores is described in the specification of U.S. Patent No. 3,283,399. This device, like the other edge winding devices described above, can be used to produce the cores made in accordance with the present invention.

Due to the resilience of the strip material, the wound helices made on these devices tends to spring back to a shape other than that which was intended. Also, due to variations in the strip's thickness, the outer edge can be rolled to varying degrees of deformation which results in varying degrees of circular curling. Because of these problems, various corrective measures have been employed.

The specification of U.S. Patent No. 4,202,196 discloses a method of forming a core with a

precise inner core diameter. This method is in response to the inherent instability of helically wound cores made in the manner described above. Another alternative to this problem is described in the specification of U.S. Patent No. 3,436,812 which punches teeth in the strip after it is formed into a helical shape. This method winds an unslotted strip into a continuous spiral and then cuts the spiral into a plurality of annularly shaped rings by severing the spiral with a single axial cut. The individual rings are then stamped to form a plurality of teeth on their inside edge. This process is intended to avoid the typical misregistration of the teeth that occurs if they are punched in the strip prior to the helical winding operation described above.

Another method, responsive to the dimensional accuracy problems discussed above, is disclosed in the specification of U.S. Patent No. 2,058,362, and specifies curved laminations which are each approximately 91 arcuate degrees in length. By assembling them with their ends abutting each other, a core is progressively built.

Individual laminations are discussed in the specification of U.S. Patent No. 4,102,040 which describes a laminated core produced by arranging a plurality of straight strips in a stack and then bending the stack to form a cylindrical core with an axial parting line formed by its plurality of aligned strip ends.

As should be apparent, helical winding of spiral cores is a means of effectively minimizing scrap in the manufacture of stator cores for dynamoelectric machines, but significant production problems are inherent in the known methods of winding them. These problems have induced several corrective techniques which, themselves, increase the cost of manufacture.

An object of the present invention is to correct the assembly problems of typical edge winding methods with minimal increase in their cost and to also improve the operating characteristics of the finished core.

According to the present invention, a dynamoelectric machine includes a core having a plurality of annular laminations, each of said laminations comprising a sheet metal arcuate section of less than 360° with the ends of said lamination being spaced apart to describe a gap therebetween, and the plurality of gaps being disposed at differing angular positions around said core.

The invention also includes a method of manufacturing a stator core of a dynamoelectric machine comprising providing a strip of magnetic material having a length substantially longer than its width, forming a plurality of teeth in a first one of its edges, said first edge being along the length of said strip, edge rolling said strip about a point to form a substantially annular lamination with said teeth extending radially inward toward said point, said lamination having an arcuate length which is less than 360°, positioning said lamination with other similar laminations to form a cylindrical core having a central bore

therethrough, aligning the teeth of each of said laminations to form a plurality of slots running axially along the bore of said cylindrical core, compressing the outside cylindrical surface of said core to a preselected diametrical dimension, and fastening said laminations together to form a unitary core.

Conveniently, this invention relates to the production of stator cores for dynamoelectric machines and, to the manufacture of edge wound laminated cores that are dimensionally accurate and have improved operating characteristics.

In accordance with the present invention, prepunched strip material is wound into a helical shape by any suitable method such as the those described above. Instead of a continuous helix, however, the strip can be wound into segments that are each slightly less than  $360^\circ$  in arcuate length. This can be accomplished by beginning with straight strips of the proper predetermined length or, in the alternative, by severing the circular helix at the proper angular position to result in the generally circular shapes which comprise approximately  $359^\circ$  of a complete annular ring.

Rings made in this manner are then stacked together to form a cylindrical core. Since each individual ring has prepunched teeth on its inner edge, the teeth can be aligned to form axially running grooves, or slots. This registration can be accomplished by stacking the individual laminations on a mandrel which fits inside each ring and has radially extending splines which fit into the slots between the teeth of the rings.

Since each ring is less than  $360^\circ$  of a circle, it can easily be deformed to form a dimensionally accurate cylindrical core when associated with other similarly made rings. When a core is thus formed, the rings can be fastened together in any suitable way to produce a stator core which is dimensionally accurate and has proper slot registration.

As a further improvement, the electrical properties of a core made in accordance with the present invention can be significantly improved by producing the straight strips by stamping them from rolled sheet metal in such a way as to have the direction of rolling run in a parallel direction to the extension of the teeth from the strip or, in other words, perpendicular to the strip's length. As the strip is edge rolled, the outer edge of the circularly shaped ring is worked so as to orient the grain structure of this outer edge in a circumferential direction or generally parallel to the strip's length while the grain structure of the teeth remains unchanged.

A core made in accordance with the present invention can thus comprise a tooth section with radially oriented grain structure and an outer, or yoke, section with circumferentially oriented grain structure. This grain structure orientation results in superior permeability and lower iron losses in the finished cores.

Since cores made in accordance with the present invention are made from straight strip

material, two strips can be punched from a thin sheet of metal in such a way as to further minimize scrap.

The teeth of one strip can be arranged to fit in the slots of an adjacent strip on a sheet of material prior to the stamping operation. The strips, by facing in opposite directions in a nested fashion, minimize the scrap produced by eliminating the wasted material that would otherwise be lost from between the teeth. Instead, this material becomes the teeth of the cooperatively associated strip.

For many years motor designers have used graded-slots for single-phase motors. This design principle has often, but not always, been coupled with the use of somewhat more nearly rectangular laminations to achieve a general reduction in stamping scrap. Some slots are graded or varied to achieve greater depth in the radial direction. Since constant tooth width is used, it is apparent from the geometry that greater slot width is also achieved. The main, or running, winding of the single-phase motor is inserted into these deeper and wider slots.

Conversely, the auxiliary, or starter winding operates only during the starting of the motor and may have significantly less thermal mass. It is inserted into slots which have been graded in the opposite manner, that is, shallower and narrower. In the typical graded-slot design, tooth pitch is not altered. Both main and starter teeth have identical and constant tooth pitch.

With study of the geometry, it becomes apparent that graded-slots, as just described above, are physically impossible to produce while using the tooth/slot nesting principle to yield minimum scrap. However, in accordance with the present invention, if the grading is done in the opposite manner, using variable tooth and slot pitch, a variable slot and tooth width is obtained and the advantages of graded-slots can be maintained. In order to allow the straight strips to be stamped in a nested manner, each tooth of a specific straight strip is matched by a slot in the same strip with a generally equal width. This allows the teeth to be associated in a nested manner in its generally equal slot in another straight strip which can be punched simultaneously. According to the present invention, graded slots can therefore be produced in continuous strips of material in a way to minimize scrap and make possible them being edge wound to form helical cores.

An object of the present invention is to provide a laminated core which can be manufactured with a minimal amount of scrap but which has superior magnetic characteristics to conventionally produced cores. It is a further object of the present invention to provide a core which can be manufactured with dimensional accuracy.

The invention will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is an isometric view of a core;



Figure 2 is a view of a single lamination of the present invention;

Figure 3 illustrates the way the strips may be nested during a stamping operation in which they are punched from a continuous sheet of magnetic material;

Figures 4A and 4B further illustrate the nested relationship of two straps of magnetic material along with their grain structure orientation;

Figure 5 demonstrates a straight strip as it is edge rolled to form an annular lamination; showing the resultant changes in its grain structure orientation;

Figures 6A and 6B illustrate two straight strips of magnetic material which have been punched with an graded-slot tooth configuration; and

Figure 7 depicts a graded-slot lamination made in accordance with presently known stamping techniques.

A laminated stator core 10 is shown in Figure 1. The core 10 comprises a plurality of annular laminations 12 with each of these laminations 12 comprising a plurality of teeth 14 which extend radially inward from a yoke portion 16 thereof.

Each circular lamination 12 extends circumferentially around the cylindrical core 10 for an arcuate distance which is slightly less than 360°. It has been determined that a lamination which comprises from 355° to 359° of a circle can satisfactorily produce a core 10 made in accordance with the present invention. The remaining arcuate distance that is not traversed by the lamination 12 forms a slight gap 18 between the two adjacent ends of each lamination. As shown in Figure 1, the laminations 12 are stacked in such a way as to randomly distribute their gaps 18 around the periphery of the core 10.

After the laminations 12 are stacked with their teeth 14 and slots 20 aligned to form axially running grooves, the outside diameter of the core 10 can be formed to a preselected dimension by compressing it radially inwardly while the laminations are mounted on a mandrel to produce the desired dimensions of the inside diameter of the core. Any deformation in an individual lamination 12 will be compensated by an associated change in its gap 18. Therefore, it should be understood that the core can be formed in such a way as to correct for any individual variation in laminations.

This ability to form the outside diameter of the core enables dimensionally oversized or undersized laminations to be corrected during assembly. It has been found that conventional edge winding equipment does not produce circular laminations 12 to precise tolerances and a certain amount of resiliency in the shaped lamination is to be expected.

By stacking the individual laminations 12, as shown in Figure 1, they can also be aligned over a splined mandrel which fits into the inside diameter of the laminations 12. This allows proper tooth 14 registration to be maintained during the forming process.

When the diameters are formed with dimensional accuracy and the teeth are properly aligned, the laminations 12 can then be fastened together by any suitable means such as welding or potting.

Figure 2 shows a single lamination 12 with its teeth 14, slots 20 and gap 18. The teeth 14 extend radially inward from the lamination's yoke portion 16. Between each adjacent pair of teeth 14, a slot 20 is formed which is sized to accept a stator conductor after the lamination is stacked with others to form a core. It should be apparent that the gap 18 allows the lamination 12 shown in Figure 2 to be radially compressed to a smaller diameter than illustrated in Figure 2, limited only by the size of the gap 18.

The annular lamination 12, or ring, shown in Figure 2 can be manufactured by any of the edge winding techniques described above. It can be severed from a continuous helical coil or rolled from a precisely measured straight strip whose length has been determined to result in the proper circumferential dimension required to produce a lamination which has a predetermined gap and is of a preselected circular configuration.

When each of the laminations are rolled from individual straight strips of material, as discussed above, additional advantages can be realized in the magnetic characteristics of each lamination and therefore of the completed core. Figure 3 shows a sheet 30 of rolled sheet material from which laminations are to be made. Sheet material of this type is normally rolled in the direction shown by the arrow R<sub>1</sub>. This rolling, which is inherent in the manufacture of rolled sheet material of this results in a grain orientation of the material which is in the direction of the arrow R<sub>1</sub>.

Also shown in Figure 3 are four typical straight strips 32a, 32b, 32c and 32d, which are to be eventually edge-wound into circular laminations. The strips are stamped from the sheet in such a way that their individual lengths are perpendicular to the direction of grain orientation R<sub>1</sub>. Figure 3 also demonstrates the cooperative association of strip 32a with 32b and of strip 32c with 32d. Each of these pairs comprises two nested strips wherein the teeth of one strip is disposed in the slot of its associated strip to minimize scrap. It should be understood that, for teeth which are not rectangular, total elimination of scrap is not possible. However, the nesting of associated strips, as shown in Figure 3, minimizes the amount of scrap produced for any particular tooth design.

It should be understood that many tooth designs are not rectangular as shown in Figure 3. Instead, some are shaped with rounded bottoms as shown in Figure 2. However, since the present invention is not dependent on a particular tooth configuration, rectangular tooth shapes will be illustratively used herein.

Using straight strips 32a and 32b from Figure 3, Figures 4A and 4B further show their nested relationship as the two are parted. Arrows R<sub>1</sub> illustrate the original direction of grain orientation,

as described in conjunction with Figure 3 and the discussion above. As Figures 4A and 4B clearly show, the grain orientation is the same throughout both straight strips and is consistent in both the tooth 14 and yoke 16 portions of the strips. It should be understood that this particular orientation of grain structure in the straight strips is due to both the rolling direction by which the roll of sheet metal (reference numeral 30 of Figure 3) was produced and the orientation of the straight strips on that sheet metal. As Figure 3 illustrates, the straight strips 32a, 32b, 32c and 32d were punched from the sheet 30 so that their lengths were perpendicular to the direction of rolling R.

Figure 5 illustrates a strip 32b of material as it is being formed into a circular, edge wound shape. It should be understood that, although no winding equipment is shown in Figure 5, any device that is capable of edge winding a straight strip, such as 32b, of prepunched material into an annular shape can be utilized.

As the strip is rolled into a circle, its outer edge is elongated and becomes thinner. This elongation is a physical necessity because of the greater circumferential distance around which the outer edge extends. When a prepunched strip is edge-rolled, it typically experiences elongation from its outer edge 50 to a point 52 just below the root of the slot 20. Between this point 52 and the root of the slot 20, the strip experiences a slight compression and, in the tooth 14 region, no material deformation occurs.

The elongation of the outer portion, or yoke 16, of the strip 32b causes the grain structure in that portion of the strip to become oriented in the direction of elongation of the strip. Arrows  $R_2$  show this new direction of grain orientation in Figure 5. It should be apparent that, since the yoke 16 is elongated and the tooth 14 portion is not deformed, the result of the edge rolling operation is to orient the grain structure of the yoke 16 in a circumferential direction  $R_2$  while leaving the grain structure of the teeth 14 unchanged and oriented in a radial direction in the annular lamination that is produced by the edge rolling operation. It should further be apparent to one skilled in the art that this selective grain orientation of the tooth 14 and yoke 16 portions of each lamination improve the magnetic characteristics, increasing permeability and reducing iron losses.

Figures 6A and 6B illustrate a variation of the present invention in which the slots 20 and the teeth 14 do not comprise a uniform pitch. This type of construction, referred to herein as a graded-slot design, selectively provides larger slots for the main winding and smaller slots for the auxiliary winding of a single phase motor. It should be apparent from a viewing of Figures 6A and 6B together that the elements and methods of the present invention are equally applicable in graded-slot designs. Of course, in order to permit the economical nesting described above, the tooth widths and slot widths must be coordinated

so that the teeth 14 of one strip 60a are cooperatively associated with the slots 20 of another strip 60b, and vice versa. It should be apparent from these figures that, even in graded-slot designs, the material saving nesting techniques described above and shown in Figures 3, 4A and 4B are applicable. It should further be apparent that the selective grain orientation, also described above, can be achieved in an graded-slot design.

Figure 7 depicts a graded-slot lamination designed for manufacture by presently used stamping techniques. It consists of slots of variable depth in order to provide slots with variable area. As explained above, the purpose of this variability is to provide large slots for the main windings and small slots for the auxiliary winding. The auxiliary winding slot 71 is clearly smaller than the main winding slot 72 with gradations therebetween. It should be obvious, by studying the geometry involved, that a pattern of varying slot depths, as shown in Fig. 7, is not physically possible to manufacture while achieving the maximum savings obtained in a double width strip having full slot to tooth meshing as shown in Figures 3, 4a and 4b. The graded-slot design of the present invention, as shown in Figs. 6A and 6B, in contrast, utilizes slots which have a constant depth and is thus manufacturable. This geometric advantage, which results in reduced material usage, accrues irrespective of the method used for edge winding or forming the strip and irrespective of the usage of the grain orientation advantage illustrated in Figures 3, 4a and 4b.

The present invention provides a laminated stator core that utilizes edge rolled laminations which result in significant material savings. It further provides a means of correcting typical malformations experienced in most conventional roll-forming methods by employing single laminated rings with a gap within each lamination. Also, the present invention makes possible a selective grain orientation within each lamination which significantly improves the magnetic characteristics of the core and the electrical performance of the resulting dynamoelectric machine. Furthermore, it is applicable to both uniform and graded-slot designs.

It should be apparent that the present invention provides a stator core that reduces manufacturing costs and improves the electrical characteristics of a dynamoelectric machine comprising it.

#### Claims

1. A dynamoelectric machine including a core having a plurality of annular laminations, each of said laminations comprising a sheet metal arcuate section of less than 360° with the ends of said lamination being spaced apart to describe a gap therebetween, and the plurality of gaps being disposed at differing angular positions around said core.

2. A machine as claimed in claim 1, including a plurality of teeth extending from each of said laminations in a radially inward direction.

3. A machine as claimed in claim 1 or 2, wherein each of said laminations is a severed portion of a helix formed by edge rolling a continuous strip of material about a central axis, said strip having a length substantially greater than its width.

4. A machine as claimed in claims 1, 2 or 3 wherein each of said laminations is formed by edge rolling straight strip of material into a substantially circular shape, said straight strip having a length which is predetermined to result in an annular lamination comprising less than 360 arcuate degrees, said length of said strip being substantially greater than its width.

5. A machine as claimed in claim 4, wherein said straight strip has a grain structure orientation perpendicular to its length.

6. A machine as claimed in claim 5, wherein each of said laminations has a grain structure orientation of its radially outer portion which is circumferential to said lamination and is generally concentric to said lamination.

7. A machine as claimed in any one of claims 2 to 6, wherein said plurality of teeth are uniformly distributed with a substantially constant pitch along the inner edge of said annular lamination.

8. A machine as claimed in any one of claims 2 to 6, wherein said plurality of teeth vary significantly in width.

9. A machine as claimed in any one of claims 1 to 8, including means for attaching said plurality of annular laminations to each other.

10. A machine as claimed in any one of claims 1 to 9 in which are provided a rotatable member and a stationary member, said stationary member having a core, with a plurality of laminations, each lamination being made of magnetic material, each of said laminations being annular and having an arcuate length of slightly less than 360°, and means for binding said plurality of laminations together to form a unitary core.

11. A machine as claimed in claim 10, wherein each of said teeth is identical in dimension to all other of said teeth.

12. A machine as claimed in claim 10, wherein a preselected number of said teeth differ substantially in dimension from preselected others of said teeth.

13. A machine as claimed in any one of claims 1 to 12, in which each of said teeth comprises a grain structure oriented radially to said lamination and the portion of each of said laminations from which said teeth extend comprises a grain structure which is oriented circumferentially to said lamination and concentric to said lamination.

14. A machine as claimed in claim 13, wherein the ends of each of said plurality of laminations are randomly positioned about the circumference of said core.

15. A method of manufacturing a stator core of a dynamoelectric machine, comprising providing a strip of magnetic material having a length

substantially longer than its width, forming a plurality of teeth in a first one of its edges, said first edge being along the length of said strip, edge rolling said strip about a point to form a substantially annular lamination with said teeth extending radially inward toward said point, said lamination having an arcuate length which is less than 360°, positioning said lamination with other similar laminations to form a cylindrical core having a central bore therethrough, aligning the teeth of each of said laminations to form a plurality of slots running axially along the bore of said cylindrical core, compressing the outside cylindrical surface of said core to a preselected diametrical dimension, and fastening said laminations together to form a unitary core.

16. A method as claimed in claim 15, in which the steps of the method comprises rotating preselected laminations about their center to prevent the ends of one lamination from being positioned proximate the ends of an adjacent lamination.

17. A method as claimed in claim 16, including providing a grain structure of said strip of magnetic material which is oriented perpendicularly to said first one of its edges.

18. A method as claimed in claim 17, including the further step of providing a grain structure of the radially outer portion of said lamination which is oriented circumferentially to said lamination and concentric therewith.

19. A method as claimed in any one of claims 15 to 18, in which said teeth are uniformly spaced along said first one of the edges of said strip.

20. A method as claimed in any one of claims 15 to 18, in which said teeth are non-uniformly spaced along said first one of the edges of said strip.

21. A dynamoelectric machine as claimed in claim 1, in which said core having a plurality of substantially circular laminations, each of said laminations having a plurality of teeth extending radially inward from said lamination, said teeth being arranged in a variable pitch configuration.

22. A machine as claimed in claim 21, wherein each of said laminations is a turn of an edge wound helix.

23. A machine as claimed in claim 22, wherein a preselected number of said teeth are larger in circumferential dimension than preselected other of said teeth.

24. A machine as claimed in claim 23, wherein each of said teeth has a radial dimension substantially equal to the radial dimension of each other of said teeth.

25. A machine as claimed in claim 23 or 24, wherein each of said laminations is less than 360 degrees in arcuate length, having two ends which have a gap therebetween.

26. A machine as claimed in claim 25, wherein said lamination has a circumferentially aligned grain structure in its radially outer portion.

27. A machine as claimed in claim 26, wherein

said lamination has a radially aligned grain structure in its teeth.

28. A dynamoelectric machine, constructed and adapted for use, substantially as hereinbefore described and illustrated with reference to the accompanying drawings.

29. A method of manufacturing a stator core of a dynamoelectric machine, adapted for use substantially as hereinbefore described and illustrated with reference to the accompanying drawings.

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